Four-Dimensional Current Experiment

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LONG-TERM GOAL

The goal of the study is to understand the role of small-scale physical processes in the coastal ocean through observations of the four-dimensional current variability. The approach combines the Florida Atlantic University (FAU) Autonomous Underwater Vehicle (AUV) technology with the UM/RSMAS Ocean Surface Current Radar (OSCR). The engineering part of the research seeks to develop, integrate and test instrumentation designed to measure subsurface current structure from AUVs. The scientific hypothesis is that subsurface and surface currents are dynamically linked through the internal wave continuum such that the four-dimensional physical environment can be constructed over a limited domain.

OBJECTIVES

Specific objectives are:

- To design and implement multiple Acoustic Doppler Current Profilers (ADCP) as part of the AUV payload;

- To evaluate side-looking ADCP beam orientations with respect to minimizing surface and bottom echo interference;

- To relate the aerial estimates of the OSCR-derived surface currents in selected cells to high-resolution subsurface current measurements acquired from ADCPs on AUVs as well as from ship- and mooring-based observations;

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- To isolate low-frequency (subinertial), wind-driven (Ekman), tidal and internal wave signals present in the surface current signals, and to relate them to the vertical structure of subsurface currents and stratification;

- To assess the role of divergence and vorticity fields associated with subinertial and wind-driven flows and their net impact on submesoscale dynamics; and

- To examine coherent structures in the upper ocean mixed layer.

APPROACH

The RSMAS OSCR radar system (VHF mode) was deployed from late June to early Aug 1999 at the South Florida Ocean Measurement Center (SFOMC) to measure the surface current field. Concurrently, subsurface current and density data were acquired on several missions during a 30-day period with multiple ADCP and CTD probes on the FAU Ocean Explorer (OEX) AUV, from the R/V *Stephan* , and subsurface moorings.

TASKS COMPLETED

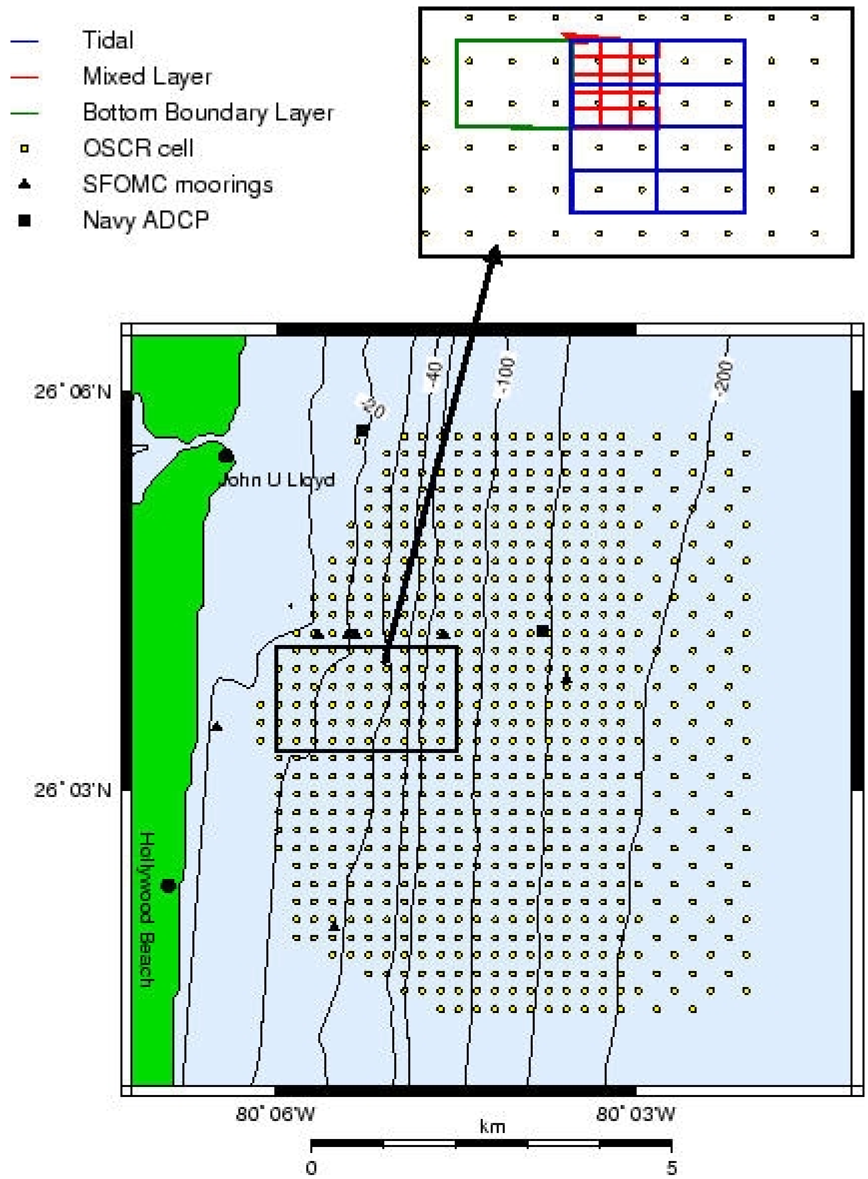
During the period of deployment in the SFOMC, a 29-d continuous time series of vector surface currents were acquired starting on 9 July and ending 7 August 1999 at 20-min intervals (Shay *et al*. 1999). The VHF radar system mapped coastal ocean currents over a 7.5 *km* x 8 *km* domain with a horizontal resolution of 250 m at 700 grid points every 20 min (Fig. 1).

The AUV-based measurements involved an OEX to map the high-resolution, three-dimensional ocean currents for periods of 12 and 24 hours within the radar domain. Measurements of the subsurface current vector from a pair of synchronized upward- and downward- looking 1.2 MHz ADCPs were the most important component of observations with the AUV. The sampling rate was every second (60Hz), which resolved horizontal scales of about 3 m in several OSCR cells. The upward-looking ADCP was programmed to have 0.5 m bins for the Mixed Layer and Tidal Missions and 1.5 m bins in the downward-looking direction. For the Bottom Boundary Layer Mission, higher resolution bins were programmed in the downward-looking ADCP.

As shown in Fig. 1, the OEX sampled a 500 *m* x 500 *m* grid (4 cells), and was programmed to map subsurface current velocities in water depths ranging from about 20 to 35 m, while maintaining a 9 m depth during two mixed layer experiments (9,27 July). The OEX occasionally surfaced to obtain differential GPS fixes that bound positional errors to within the required level (25-50 m). The time to complete one pattern was 1.5 h. The Bottom Boundary Layer Mission made repeated cross-shelf transects of 1 *km* (5 cells) separated by 500 *m* (2 cells) in the along-shelf direction over a 7 h period. During the Tidal Current Experiment, the OEX sampled the velocity structure over an area of 1 *km* (5 cells) x 1 *km* (5 cells) in water depths from about 20 to 35 m for a continuous period of 24 h while maintaining a constant depth of 9 m.

Ship-based ADCP measurements of horizontal current profiles were acquired with a 600-kHz ADCP and of the stratification with CTDs from the R/V *Stephan* during AUV operations. Shipborne CTD and ADCP measurements were acquired on a rectangular grid pattern spaced 1 or 2 OSCR cells outward from the AUV grid. The typical ship speed was 1.5 m s^{-1} such that ship track

required 1.5 to 3 h to complete. The ADCP was set at 1-m bins, producing a vertical range of about 35 m depth. Bottom tracking was possible at depths up to 85 m. The Cyclesonde Autonomous Profiler was deployed in the center of the NOVA/USF array and in the core of the OSCR domain that included bottom-mounted, upward-looking ADCPs.

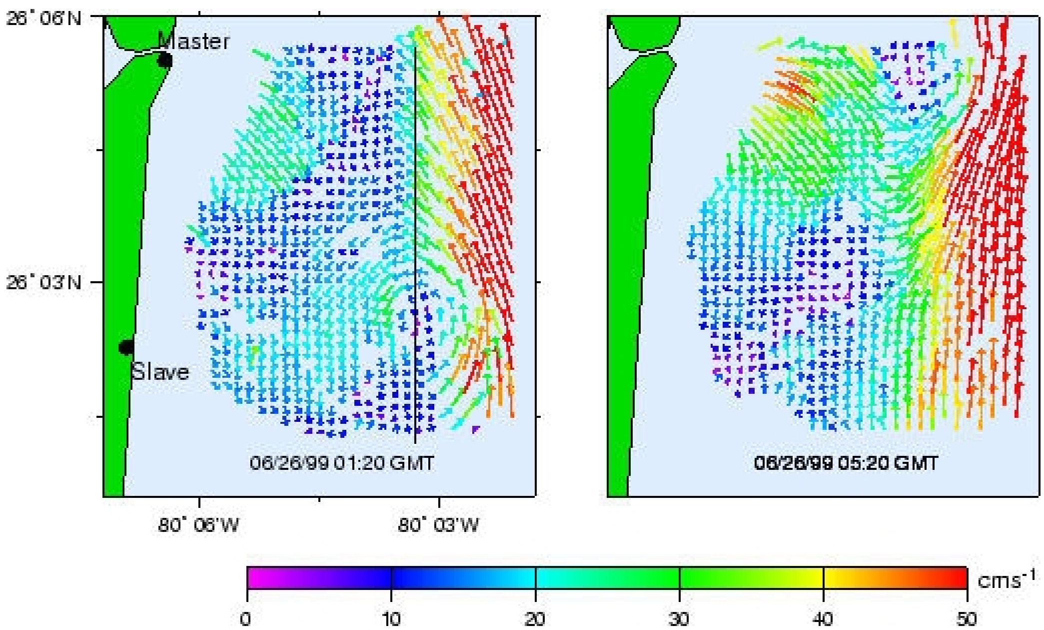


1. Multiple-nested measurement domain embedded with the OSCR grid (circles) for the SFOMC 4-D Current Experiment relative to bottom topography in meters. Master and slave sites are located at John Lloyd State Park and Hollywood Beach, respectively. Inset provides the high-resolution sampling patterns for AUV measurements relative to OSCR Cells for the Mixed Layer, Bottom Boundary Layer, and Tidal Current Missions.

RESULTS

During quiescent conditions that prevailed during June and July, surface currents reveal submesoscale vortices, frontal lobe-like structures, subsurface maxima, and Florida Current intrusions over the shelf break. Given the richness of this data set, new insights will be gained from analyzing the data sets acquired during the experiment (Smith *et al.*, 1998).

On 26 June 1999 starting at 0120 GMT (Fig. 2) , a submesoscale vortex was located along the southern part of the VHF-radar domain just inshore of the Florida Current. Surface currents within the vortex were 30 cm s^{-1} at a diameter of 1.25 km from the center (Shay *et al*. 1999). Along the inshore edge, surface currents were directed towards the south at 20 cm s^{-1}. Subsequently, the center of the ring moved about 2 km northward, and the diameter of the submesoscale vortex remained about the same about one hour later. By 0400 GMT, the ring moved 3.5 km northward from its original position. Surface currents subsequently increased to about 50 cm s^{-1} at a radius of 1.5 km from its center by 0520 GMT (Fig. 2b).



2. Surface current images from the SFOMC 4-D Current Experiment on 26 June 1999: at 0120 GMT (left panel) and 0520 GMT (right panel). Along the section in the left panel, a latitude-time series indicated a speed of 30 cm s^{-1}.

Preliminary comparisons between surface and subsurface currents indicated fairly high correlations above 0.8. The subsurface cross-shelf currents were generally weaker than the corresponding surface component a few meters beneath the surface at the mooring and along the AUV transects. According to the ship-based measurements, there was a pool of warmer water confined to the upper few meters during the first mixed layer experiment. The relationship between surface and subsurface profiler measurements is being explored to establish consistencies between the various measurements from all missions. In addition, the horizontal structure of the depth-averaged currents from the AUV data indicated a northward flow of 30 cm s^{-1} aligned with the bottom topography. These flows reversed (3 h later) in the inner-shelf and flowed westward over the outer-shelf at

speeds of about 20 cm s^{-1}. Over the six hours of measurements, current reversals suggest the possibility that this variability was due to the M_2 tidal current.

IMPACT

The data are providing new insights into coastal circulation forced by a western boundary current at the shelf-break. These data will be useful in understanding the surface current measurements with respect to high-resolution subsurface currents. The experiment demonstrated the relative importance of conducting AUV and ship-based sampling grids within a very high-resolution grid of surface current measurements from OSCR.

TRANSITIONS

Such an approach will be useful for the Fleet operating in the littoral zones, requiring adaptive sampling strategy for training exercises conducted by NAVOCEANO. The research described herein is relevant to the operational Navy communities. Modeling efforts at the Naval Research Laboratories will also benefit from these types of data sets in evaluating model results.

RELATED PROJECTS

This project, in collaboration with FAU, was one of several engineering and scientific experiments conducted in the newly established SFOMC under US Navy sponsorship. In addition, the project benefits from lessons learned from other ONR sponsored programs utilizing HF radar (*i.e.* Chesapeake Bay Outfall Plume Experiment) and the AUV measurements in support of NICOP.

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